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PRINCIPLES OF URETHANE FOAM ROOF APPLICATION,(U)
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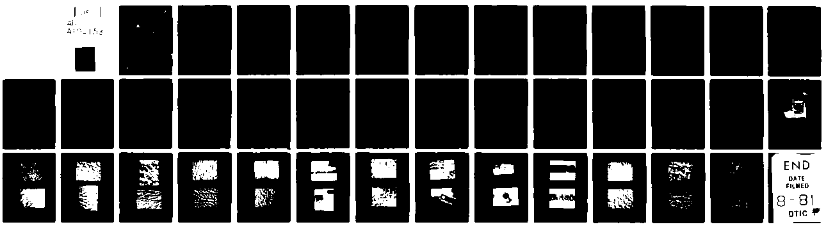

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NAVAL CONSTRUCTION BATTALION CENTER
Port Hueneme, California 93043

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CORPORATE AUTHOR: Keith H. Coultrap
Coultrap Consulting Services, Inc.

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FOREWORD

Although sprayed polyurethane foam (PUF) roofing systems have been used successfully for about 15 years, they are considered by many to be new. Problems which have arisen with these roofing systems have resulted from either (a) use of improper materials, (b) inadequate specifications, or (c) poor application.

The Civil Engineering Laboratory has prepared this report to assist those responsible for preparation of specifications, including materials, application, and quality control. It is also intended as instructional material for inspectors.

PRINCIPALS OF URETHANE FOAM ROOF APPLICATION

I. INTRODUCTION

Polyurethane foam, based on chemical technology that grew out of the rapidly accelerated technological developments during World War II, depends upon the formation of a high molecular weight polymer (or plastic material) derived from the reaction of a hydroxyl (OH) bearing resin or polyol with a chemical substance containing isocyanate (NCO) groups. In modern technology, the reacting chemicals contain a fluorocarbon blowing agent (R-11) that is vaporized at the proper time and rate by exothermic heat generated by the reacting chemicals. The exothermic heat generated causes the R-11 to cellulate the reacting mass as it changes from liquid to solid state, resulting in a foamed or cellulated material which can be either flexible or rigid, depending upon the chemicals selected as the starting materials. This discussion will be limited to rigid polyurethane foam and more specifically to sprayable materials.

As rigid urethane foam technology developed, it was recognized that certain properties of the materials could be utilized to advantage in roofing systems for building construction. Sprayed urethane foam roofing systems offer the following advantages: (1) a monolithic, seamless material; (2) a relatively strong and lightweight high quality insulation; (3) superior laminar self-adhesion to all known roof deck materials; (4) because it is applied as a liquid, all cracks, openings, splits, and similar imperfections are completely filled and sealed as the expanding urethane foam reaction is completed; (5) the liquid-to-solid expansion property also enables it to be self-flashing, which eliminates the need for metal counterflashing, masonry reglets, and wood or metal cants; and (6) it can be placed in variable thicknesses to provide improved drainage.

Over the past 15 years, the use of sprayed foam in combination with liquid applied protective coating systems has increased in importance as a method of providing roofing insulation and weather protection in building construction. Its usage in roofing, however, has not been trouble free for several pertinent reasons.

Since the spraying of polyurethane foam insulation involves the manufacture of a roof system on the job site, the process is subject to various environmental factors. The inability to control environmental conditions is probably the one greatest disadvantage to the system. In addition to proper specifications and materials, it is essential that the contractor makes application under the best conditions possible and that he uses good procedures. It is in this area that proper knowledge is required to assure satisfactory foam roof construction.

Fortunately, properly operated commercial spray equipment for application of both foam and coating materials provides excellent control over ratios of materials, temperatures, and pressures. Therefore, one important aspect is to assure that the equipment used by the contractor is well maintained and performing properly. Modern spray foam systems are generally supplied as two component materials which can be properly metered through the equipment on a "one-to-one" basis by volume. For the best application, the manufacturer's recommendations for material temperatures in the spray equipment should be followed to the letter.

It is the practice of the industry to identify the isocyanate material as the "A" component and the resin or polyol material as the "B" component. However, certain manufacturers use selected code numbers for identification of the two components. Designation of the foam components, as well as the coating materials, should be included in the specifications. The specifications usually require that the foam have a given density in pounds per cubic foot, with the A and B components sprayed in a ratio of "one-to-one." The contractor should not be allowed to vary the density in the field by changing formulation ratios in the spray equipment, because proper formulation ratio is essential to obtain other required properties of the applied foam. Although slight variations in density will result from mechanical tolerances of the spray foam equipment, foam formulations generally provide proper results as long as the ratio accuracy of the A and B components is within ±2% by volume.

It is the fluorocarbon blowing agent (R-11) captured in closed cells during formation of the rigid foam which contributes directly to the insulation quality (high thermal efficiency). Foam density is also dependent upon proper formation of closed cells containing R-11. The R-11 is typically included in the B component and must not be lost prior to use. The A component will react with water, as well as with the B component, thus destroying its effectiveness. For these reasons, it is imperative that material at the job site be stored in accordance with the manufacturer's recommendations.

II. SUBSTRATE PREPARATION

Any roof deck or roofing surface on which urethane foam is to be sprayed must be securely fastened to the substrate to preclude wind uplift or tear off. Surfaces to which foam is to be sprayed must also be clean and dry. A nominally clean surface is one that is free of loose rust, scale, grease, or other contaminants. A dry surface is one that is free of visible moisture. A moisture meter such as that shown in Figure 1 may be calibrated to verify surface dryness. For example, it can be established that a given reading with such a meter indicates acceptable dryness.

A. New Roof Decks

1. Metal Surfaces. Metal surfaces having loose scale or rust must be cleaned in accordance with Steel Structure Painting Council Bulletin SP-63 Commercial Blast Cleaning. If free of rust or loose scale, the surface may be cleaned by use of air jet, vacuum equipment, or with a hand or power broom to remove loose dirt. Grease, oil, or other obvious contaminants must be removed by use of a proper chemical solvent.

If a fluted metal roof deck is employed, a suitable method of covering or filling of the flutes is required. In addition, any application of sprayed foam to fluted decks must comply with current fire safety criteria, such as those specified in DOD Construction Criteria Manual 4270.1M and/or DM-8, Fire Protection Engineering.

Priming of surfaces with weathered or chalking paint may be required. In such cases, the recommendation of the foam or coatings manufacturers should be followed.

2. Concrete Surfaces - Precast, Prestressed. Sprayed foam generally adheres well to clean, dry concrete surfaces. Form oil, other oil, grease, and form release agents must be removed by the proper chemical solvent. Loose dirt may be removed by air jet, vacuum equipment, or brooming. If washing with water is used, the surface must then be dried prior to foam application.

Concrete decks may have joints or irregular surfaces that require remedial procedures prior to foam application. Joint opening of more than 1/4 inch between mating panels of beams should be taped prior to foam application. Similarly, mating edges of precast or prestressed beams offset in their level plane more than 1/2 inch may require special treatment.

In some cases, priming may be required prior to foam application. This will depend on the actual job conditions and the recommendations of the foam manufacturer.

3. Concrete Surfaces - Structural Poured-in-Place. Most aspects of substrate preparation (including priming) is the same for structural concrete decks as for precast or prestressed decks. Form oil, other oil, grease, and form release agents should be removed as in 2 above. Loose dirt may be removed as in 2 above.

Wood float or trowelled surfaces which are clean and dry are generally acceptable substrates for sprayed foam.

4. Concrete Surfaces - Lightweight Fill (Perlite, Vermiculite). Particular attention must be paid to the moisture content of the lightweight fill to be sure that it has dried sufficiently prior to foam application. Contaminants should be removed as in 2.

Loose granular surfaces must be hardened, such as by use of a low viscosity epoxy primer which will penetrate and harden the surface. The surface must be smooth and hard.

5. Wood Surfaces - Plywood. All untreated and unpainted surfaces should be primed with a good grade exterior primer recommended for the purpose in order to minimize problems with moisture absorption and eliminate potential foam adhesion problems. Primer should be applied in accordance with the manufacturer's recommendations. Plywood joints in excess of 1/4 inch should be taped or filled with a suitable caulk sealant prior to foam application. Deck must be dry and free of loose dirt, grease, oil, and other contaminants prior to application of primer or foam.

All grease, oil, or other contaminants on the primed surface must be removed by a method that does not remove previously applied primer. Loose dirt can be removed by use of air jet, vacuum equipment, hand or power broom. No washing should be permitted.

6. Wood Surfaces - Tongue and Groove (T&G) Decking, Sheathing, Planking. When T&G decking, sheathing, or planking is to be foamed, a plywood or sheeting overlay may be required due to potential shrinkage cracking from drying and aging of the deck. When overlay materials are used they should be nailed on maximum 12-inch centers with properly sized annular grooved nails. Where the overlay is plywood, all items in paragraph 5 shall apply. In some cases, a non-wood type overlay may be employed requiring special priming. In any event, all standards of a clean, dry deck shall apply.

B. Existing Built-Up Roofing

The replacement or repair of an existing roofing system is a many faceted problem. Each roof must be examined to determine the degree of deterioration, extent of any wet insulation, type of materials used, soundness of the roof structure, and any existing drainage problems. The existing membrane should be mechanically secure and the surface should be clean and dry. Consideration must be given to these items before specific recommendations can be made regarding partial or complete removal of the existing built-up membrane and installation of a sprayed foam roofing system. Although sprayed foam has been used successfully for partial repair applications to other roofing systems, such use can introduce a question of divided responsibility for the roofing system should subsequent leaks occur.

1. Gravel Surfaces. Prior to foam application, all existing non-imbedded gravel or slag surfacing material should be removed by means of stiff bristle street broom or powered mechanical sweeper.

CAUTION: Care should be taken not to accumulate large amounts of gravel or slag in any one place that might overload the roof deck structure.

Areas where cold application materials may have been previously applied should be examined. Where present in excessive amounts, such as mounds or puddles, these materials should be removed down to existing roofing felts. All loose dirt and dust remaining after gravel removal should be broomed and vacuumed from the roof. No washing of the roof should be permitted. All blisters should be cut and repaired. Water-saturated insulation and other spongy areas should be located and removed and loose felts should be secured so that the surface will provide a clean, dry surface and a secure base for foam application.

It should be determined that proper flashing with sprayed foam can be made to existing vents, skylights, flashings, drains, scuppers, and other openings or penetrations, and requirements for this included in the specifications. Supporting members of roof-mounted equipment such as air conditioners, evaporative coolers, fans, and ducts should be examined to assure that they can be properly flashed with sprayed foam. Existing low areas where water ponds and areas with obviously poor drainage to roof scuppers, drains, or roof edges should be considered for correction by tapering the sprayed foam.

2. Smooth Surfaces. With the exception of the gravel or slag removal defined in Paragraph 1, all other items of Paragraph 1 shall apply.

III. FOAM QUALITY

Once proper substrate or surface preparation has been achieved, proper inspection will frequently be a determining factor in the success or failure of a urethane foam roof application. There are many factors which must be considered and observed to assure that application of high quality foam is achieved. It is also important to recognize that the

foam insulation applied is the base for the ultimate application of a protective coating system. The quality of the finished system is highly dependent upon the proper application and properties of the in-place foam.

Proper application of sprayed foam requires a highly skilled and trained operator. Equipment and materials available in the modern technology can provide satisfactory results, but it is the ability and willingness of the contractor to exercise proper controls over various job site related factors which frequently accounts for the difference between success and failure. For this reason, it is imperative at the outset that the contractor has the proper equipment and materials at the job site and that he knows and understands acceptable conditions for good foam application. The minimum quality level acceptable should be established with the contractor before the foam application is started.

A. Surface Texture and Quality

One of the best visual indicators of a good foam application is the appearance of the surface profile or texture. Surface texture of sprayed foam is a function of many variables, but there are three principal contributing factors: (1) equipment adjustments, (2) environmental effects, and (3) applicator skills.

Terms used to describe foam surface texture and quality are listed below:

Smooth - See Figure 2

Orange peel - See Figure 3

Coarse orange peel - See Figure 4

Verge of popcorn - See Figure 5

Popcorn - See Figure 6

Treebark - See Figure 7

Pinholes or blowholes - See Figure 8

Rippling - See Figure 9

For purposes of this section it is assumed that all equipment is operating properly and that material ratios are correct. It is also assumed that the equipment is of the type that has variable controls for adjusting material pressures and temperatures.

1. Equipment Adjustments. Based on the above assumptions, the correct temperature and pressure of the materials contribute most significantly to proper spray pattern. A full and proper spray pattern enables the spray applicator to make uniform passes of mixed material that rises steadily as it is applied to the advancing foam front. For a given pressure, materials that are too cold will cause a rather narrow spray pattern which drives into the rising deposited foam and causes dimples, holes, roughness, and/or ridges. The overall effect is a popcorn or, in an extreme case, a treebark foam surface. If the temperature is only slightly low, adjustments of the material pressure or the spray gun valving rod can correct the pattern.

If the materials are too hot, the foam deposited will be reacting too fast to permit levelling, and a verge of popcorn surface will tend to develop, even though the spray pattern is full.

Part of the training of a skilled foam applicator is to recognize spray pattern problems and how to adjust for them. The symptoms listed above should help one recognize the causes for foam with improper texture.

2. Environmental Factors. Modern spray foam material systems have been formulated to provide different speeds of reaction at some given or expected surface temperature upon which the foam will be applied. This factor is referred to as the "cream time," measured in seconds of time at a given temperature of application, that the "A" and "B" components will begin to react or foam after being mixed through the spray gun. For example, contractors frequently refer to a 4-second, 6-second, or 8-second foam. These rates of reaction (cream times) can be changed to some degree by material temperatures, but it is the responsibility of the contractor to select a system with an appropriate cream time for the environment where the foam application is to be made. Selection of an improper cream time can usually be judged by certain surface texture factors. If the cream time is too short and the environmental conditions are too warm, the applicator will experience difficulty in obtaining a smooth or orange peel surface. Typically, the texture will trend to coarse orange peel and beyond, depending upon the conditions. A foam with a faster or shorter cream time will not be quite as sensitive to wind velocities that may be present when foam is being applied, however, the benefit indicated is marginal. It is better to use a foam system that fits the proper temperature conditions and to limit the application to acceptable wind conditions.

When the cream time is too long, the surface texture of the foam may be very smooth, but the surface skin may be quite dense and the density of the foam may be affected. As a consequence, more spray passes will be required to obtain the desired foam thickness. A long cream time will also present problems when the foam is sprayed on vertical surfaces, such as parapet walls, flashings, and cants. The effect will be for the material to run or sag before proper foaming begins, which tends to lead to treebark in extreme cases. When foam is applied to vertical surfaces it should foam straight out with no visible slump or sag. Long cream time foam is more susceptible to wind effects on the surface, and in extreme cases a ridging or rippling effect will be obtained much the same as wind on water.

Aside from temperature, winds often create a most difficult situation. As indicated above, wind not only affects the surface texture of applied foam but also causes overspray, which is a serious problem. Overspray can damage surfaces not intended to be sprayed, such as other buildings, vehicles, and equipment, and excessive overspray deposited on foam already in place causes an irregular surface which interferes with subsequent foam or coating application. Practical experience has shown that foam should not be sprayed when wind speeds are over 12 miles per hour without some form of windshield and should not be sprayed at all when wind speed is over 25 miles per hour. It is important to evaluate potential damage that might occur due to overspray in combination with the surface texture quality of the foam being applied. Some relief can be obtained from overspray problems by proper masking protection, but it

is essential that the quality of the foam applied under windy conditions be carefully controlled. Rippling (see Figure 9) can result from spraying at excessive wind speeds.

3. Applicator Skills. Given proper materials, equipment, and conditions of application, the skill of the applicator of the foam is one of the most important factors in determining the surface texture and uniformity of foam thickness. It is important to determine as soon as possible after foam application begins that the applicator possesses the skills and experience to make a proper application. These skills must include the knowledge of proper adjustments to the equipment, the foam material being used, and the limits that environmental factors may impose. He must also be willing to follow proper procedures.

It cannot be emphasized too strongly that foam application should be suspended immediately if the results being obtained cast doubt in the above areas. It is far better to prevent bad application than to correct such conditions after the foam is in place. One can soon tell how competent the applicator is by observing to what extent the foam passes are applied to a uniform thickness of 1/2 inch to 3/4 inch per pass and the degree to which the surface texture of the foam exhibits an acceptable "smooth" or "orange peel" finish. Application should also be judged by the uniformity of foam applied to transition points of flashings, cants, roof edges, equipment mountings, etc. A good applicator will demonstrate a proper overlapping of the spray pattern which results in a uniform planar level of the foam, free of "ridging" or "rippling" (sometimes referred to as a "wash board" effect).

To repeat, it is vitally important that the acceptable level of foam quality be established with the applicator(s) during the early stages of application.

B. Spray Foam Equipment and Material Problems

Consideration was given to foam quality factors independent of equipment malfunction and improper materials or mixtures in Section III.A. This section is intended to aid in recognizing problems caused by materials being off ratio and/or due to materials being too old, out of shelf life, or reacting improperly. The effects of the latter problems can usually be discerned through improper foam surface texture, color, or where the foam is soft and spongy or hard and brittle. In certain situations the surface of the foam may also exhibit blow holes and/or pinholes.

With modern spray foam equipment, the applicator will not be able to develop a consistently proper spray pattern through the spray gun if the metering or proportioning pumps seriously malfunction, for various reasons, or if materials are not supplied to the proportioning pumps on a constant basis. However, short term blockage of materials in the spray gun or momentary metering pump cavitation problems may escape detection by the applicator which will result in deposit of poor quality foam in relatively small areas. At times an operator will see a short break in the spray pattern and decide that nothing is wrong and will proceed with the work. However, if it is observed that there are constant fluctuations in the spray pattern or the appearance of the foam being applied is abnormal, the work should be stopped until the cause is determined.

If the materials being sprayed are too old or have deteriorated due to chemical shelf life, early detection by observance of poor foam quality is normally possible. In the event of such an occurrence, no job site remedy is usually available and the material(s) should be replaced. It is obvious that the latter problem can be avoided if it is determined, prior to application, that the materials are within the shelf life recommendations of the supplier and that they have been stored properly on the job site.

1. Excess Isocyanate or "A" Component. The effects of foam applied which is off ratio or misproportioned with respect to the isocyanate component are more difficult to discover unless the condition is extreme. In fact, foam applied with slight excesses of isocyanate is not as seriously affected as when there is excess polyol, because in the former case, the polyol is totally reacted. The more extreme condition of excess isocyanate, such as shown in Figure 10, will exhibit one or more of the following effects:

(a) Dark in color
(b) Smooth hard surface
(c) Irregular glassy cell structure
(d) Friable and/or brittle foam
(e) Improper density
(f) Improper rise

Such foam should be removed and replaced because normal physical properties will not be obtained. No coating over this type of foam should be permitted.

2. Excess Polyol or "B" Component. The effects of foam applied which is off ratio or misproportioned with respect to the polyol component will be one or more of the following:

(a) Light in color

(b) Slow and/or insufficient rise

(c) Soft and spongy

(d) Improper cell structure

(e) Highly mottled or coarse orange peel surface texture

(f) Blow holes or pinholes

Foam of the type described will not have normal properties of strength, density, or insulation value. Such foam should be removed and replaced and coating over this foam should not be permitted. Figure 11 shows a typical resin-rich surface (excess polyol).

3. Aged or Improper Materials. The effects of using foam materials which are aged (beyond shelf life), have been stored improperly, have been improperly formulated, have lost blowing agent, or have moisture contamination are described below. Fortunately, such problems are infrequent, and when they do occur there is no mistaking their effects. It is highly unlikely that any good foam will be obtained. The applicator cannot make adjustments to improve it. The obvious effects are one or more of the following:

(a) Slow rise or reaction

(b) Poor cell structure

(c) Improper color

(d) Blow holes or pinholes

(e) Improper density

(f) Frequent clogging of spray foam equipment

(g) Poor spray pattern

(h) Friable foam

(i) Foam which is slow to cure

(j) Poor physical properties

No coating application should be permitted on such poor quality foam. It is essential that all such materials applied be removed and the area refoamed.

C. Application of Foam Over Improper Surfaces

Aside from previous factors that have been explained with respect to surface preparation and impact of environmental conditions on foam quality, this section is intended to enable personnel to recognize foam problems that can occur due to the effects of various surface conditions primarily caused by weather conditions. It is important to recognize that the surfaces involved include the foam previously applied which is to receive additional foam, as well as the originally prepared roof deck or substrate. It is assumed for purposes of this section that the roof deck or substrate is secure and clean as described in Section II.

1. Damp or Wet Surfaces. One of the most fundamental requisites in the successful application of sprayed urethane foam is that the foam be applied to a dry surface. This point should never be compromised. As explained previously, moisture will react with the isocyanate component of the foam formulation. Any moisture that reacts with the isocyanate component steals isocyanate from the formulation intended to create the urethane polymer and therefore in extreme cases can be the cause for an off-ratio foam in favor of excess polyol. Such a foam will have improper physical properties, especially at the foam surface interface where the reaction occurs, and will affect adhesive and/or the cohesive strength of the foam. The latter effects usually lead to blister formation at some later point in time.

When water or moisture reacts with the isocyanate component, a by-product of the reaction is the formation of CO_2 (carbon dioxide) gas. This gassing causes the foam surface to exhibit high porosity where the reaction occurs. Severity of the condition described varies with the amount of moisture present, but it does provide a visible means of determining whether moisture was present when the foam was sprayed. Surface effects of foaming on a wet surface are shown in Figure 12.

The following rules should be applied to preclude problems with moisture:

(a) No foam application should be permitted in the presence of rainfall, mist, fog, snow, or visible moisture.

(b) Moisture conditions of surfaces suspected to be improper should be checked with a moisture meter, such as shown in Figure 1. No foam application should be permitted where moisture meter readings are in excess of a predetermined amount, such as ten percent (10%).

(c) No foam application should be permitted if the dew point is less than 5°F above the surface temperature of application, as measured by a surface pyrometer such as shown in Figure 13.

One practice that usually results in good foam application is to try to apply all foam, in a given area, to the desired thickness on a "same day" basis. On large jobs, of course, it is impossible to apply all of the foam to the desired thickness in one day. Under such conditions, it is better to complete one section of the roof than to try to apply some foam over a large area. The former situation will require that lead edges of foam be tied in at a later time. When such is the case, it is very important to take moisture meter readings at the existing foam surface lead edge to be sure that conditions are proper.

Urethane foam has a low heat capacity and, therefore, foam surfaces that become wet or damp will usually be slower to dry than adjacent unfoamed roof deck surfaces. Often the roof deck surface will be dry enough for application of foam before existing applied foam reaches the same dry condition. Usually, the contractor will leave such an area open during the course of a day's work to permit drying and tie in the existing lead edge at the end of the day. Experience has shown that blistering in urethane foam roof systems is often caused by moisture present on surfaces at the time of foam application.

2. Surfaces That Are Too Cold. In Section I, exothermic heat generated during foam formation was mentioned. A surface that is colder than that recommended by the foam supplier constitutes a heat sink. Aside from the possibility of a cold surface being damp, surfaces that are below 60°F usually create a heat sink which causes a problem with spray foam systems that rely totally on R-11 blowing agent for cellulation. The difficulty encountered is that the exothermic heat generated in the formation of the urethane polymer is required to vaporize the R-11, which has a boiling point of approximately 75°F. A heat sink can steal or drain off this heat to the extent that no foaming takes place initially and the mixed and sprayed chemicals, reacting very slowly, form a thin film on the surface.

When this occurs to a substantial degree, a smooth thick skin or rind will form between the surface of application and the foam above it. This layer of material will exhibit little or no cellulation and will be friable, hard, and brittle. Usually, the condition described will affect adhesion and can cause foam blistering at a later time. This condition may develop when the roof deck temperature drops to about 60°F, and it may be necessary to halt foam application.

It is important to note that this effect is usually predominant on the original roof deck surface of foam application in contrast to application over previously applied foam. The foam in place, being an insulator, creates no heat sink, so subsequent passes of sprayed foam are trouble free, providing that the foam surface is properly dry.

The key to watch for is less than normal foam rise on first pass application and/or evidence of a wet-looking liquid film at the surface. The effect of this very slow reaction is illustrated in Figure 14.

3. Surfaces That Are Too Hot. In some geographical areas, roof deck surface temperatures may be so hot that a special foam formulation is required. The two effects visually observed are (1) an increase in foam density due to loss of R-11 blowing agent and, (2) blow holes or pinholes in the foam. Effects of applying foam to surfaces which are too hot are shown in Figure 15.

Strange as it may seem, the foam surface texture can vary from smooth to verge of popcorn, depending upon the temperature level at the surface to be foamed. It is difficult to be specific about hot surfaces, due to formulation variables. Except when the contractor uses a foam with a totally improper cream time, the problem is not normally severe at roof deck temperatures up to 120°F. In climates where surface condensation is not a problem, a solution is to limit spray foam application to early morning, late afternoon, or late evening. The principal adjustment is to select a foam system with a longer cream time in combination with some reduction of material temperature in the spray equipment.

D. Foam Skin Sunlight Degradation

Ultraviolet (UV) light from the sun degrades urethane foam which has not been protected with coating. The longer the exposure, the more severe the degradation, as shown in Figure 16. Specifications tend to vary in describing periods of time that are permitted for exposure before coating. However, it is important to understand the conditions that create a basis for acceptance or rejection.

Generally, it can be stated that lower density foams undergo more rapid surface deterioration than higher density foams. It is also important to consider the extent of UV exposure with respect to time. It is obvious that the condition is more likely to be a problem in geographical areas of high solar exposure than in areas where there is more cloud cover and fewer days of sunshine. The primary concern is that the degraded foam surface does not adversely affect adhesion of subsequently applied foam or coating.

Effects of UV degradation are easy to observe. Initially, the surface will darken in color and as the condition progresses, the surface will show evidence of dusting or friability and will eventually become burnt orange in color and show evidence of erosion. Normally, there will be no harmful effects of UV degradation within a period of three days (72 hours). However, once this time has passed, foam surfaces should be examined for the effects described.

The best way to prevent degradation of foam is to make "same day" application of full foam thickness where multiple passes of foam are required and to apply the first coat of protective coating that same day. As stated above, the foam must be coated within 72 hours. If the

foam remains uncoated for even one day, the surface should be examined to be certain that objectionable degradation has not occurred and that the surface is dry before spray application is resumed. Degradation rate will be reduced when work is interrupted by rain or cloudiness, but special attention must be given to assure surface dryness before work is resumed.

If surface UV degradation is present to the extent that dusting or friability is observed, the foam surface should be thoroughly brushed with a stiff bristle broom, mechanically scarfed or sanded, and cleaned of loose material before further application of foam or coating is permitted. In the case where foam is ready for coating, a light pass of foam should be applied to the prepared surface to reseal the surface and provide a proper coating base.

E. Foam Thickness Measurement

Foam thickness should be continually monitored as application proceeds in order to assure that specification foam thickness is achieved for insulation requirements, for creating proper slope, or for elimination of low areas. The most satisfactory and easiest method is to use a thin or small diameter probe, such as a needle, thin wire, or small knife blade. Either the probe can be pre-marked for thickness or a separate rule can be used to indicate thickness. Since the foam will be sealed with a coating, use of a thin probe will cause no problems. Use of welding rods, nails, or large diameter objects as probes should not be allowed because the larger holes, not likely to be sealed by the coating, may become sources for water penetration.

A very accurate but tedious method of measuring foam thickness involves use of a "transit level." The instrument can be placed at any convenient location on the roof structure and, by using a surveyor's rod, foam thickness can be determined on slope lines and low areas relative to points of reference such as drain receivers, roof edges, and equipment mountings. In certain cases, preliminary reference points may be marked, before foam application begins, to aid in overcoming special problems. In some situations, a combination of the transit level method and a probe is desirable. Readings with a transit level can be made from distances of two hundred feet or more, depending upon the quality of the instrument.

Screed blocks made from foam or string lines should not be allowed to monitor foam thickness because they are not very accurate and usually interfere with foam application. They may also give a false indication due to accumulation of foam overspray.

IV. COATING QUALITY

Although samples of sprayed foam have been immersed in water for various periods of time with little evidence of water absorption, tests such as these do not include the vapor drive caused by pressure and temperature differentials found on a roof. Typical sprayed foam is fairly water resistant but should not be considered as waterproof in and of itself. An elastomeric protective coating, usually applied as a liquid, is required for true waterproofing, as well as for protection

against UV degradation from sunlight (as explained in Section III.D). Although there are other ways to protect sprayed foam, this document deals only with liquid applied elastomeric protective coating systems.

Proper application of the protective coating system is equally as important as proper foam application, since both are needed for a complete foam roofing system. Personnel involved with foam roofing systems should know and understand the factors that result in quality coating application.

A. Coating Thickness

The thickness of a given coating can be determined either as it is being applied (wet) or after it has cured (dry). Wet film measurement is sometimes preferred because no repair of a cutout is required as in the case of a measurement after the coating has cured. If wet film measurement indicates the coating is too thin, the contractor merely adds more. A dry film measurement consists of taking a small cut of the material (unfortunately also including some of the foam) and using a special instrument to measure dry film thickness. Any deficiency in thickness must then be added and the small hole must be appropriately patched. A combination of both wet and dry measurements is recommended. Thickness of coatings is measured in mils, with one mil equal to one one-thousandth of an inch (0.001 inch). Figure 17 shows a wet film gauge and Figures 18 and 19 show typical dry film thickness gauges.

For any given rate of application of coating (such as 2 gallons per 100 square feet), the final dry film thickness in mils is a function of the percent solids by volume (also called "volume solids"). The rate of application and the volume solids are supplied by the manufacturer of the coating.

Two equations involving volume solids are shown below.

$$\%\text{ volume solids} \times 0.16 = \text{dry mils/gal/100 sq ft} \tag{1}$$

$$\frac{100 \times \text{dry mils}}{\%\text{ volume solids}} = \text{wet mils} \tag{2}$$

Example (1): Assume that the specifications call for the coating to be applied at 2 gal/100 sq ft using a two-coat application; also assume that the volume solids is 60%. Using Equation 1:

$$60\% \times 0.16 = 9.6\text{ dry mils/gal/100 sq ft} \tag{1}$$

Then for each one gallon of coating applied, the dry mil thickness should be 9.6 or 9.5 mils; for 2 gallons of coating, the dry film thickness would be 19 mils. Equation 2 provides equivalent wet film thickness.

$$\frac{100 \times 9.5}{60} = 15.8\text{ or }16\text{ mils (wet)/coat} \tag{2}$$

For each coat, then, the wet film thickness should be 16 mils.

Example (2): Assume that the specifications call for a total dry film thickness of 30 mils, applied in two coats, and assume that the volume solids is 55%. Only Equation 2 is needed:

$$\frac{100 \times 30}{55} = 54.5 \text{ wet mils (total)} \qquad (2)$$

Since the coating is to be applied in two coats, wet film thickness per coat is 27-28 mils (one-half of the amount shown above).

It should be noted that even though the applicator sprays the specified amount in terms of gallons per 100 square feet, he may have to spray more material to compensate for overspray losses. Other items of importance in this regard are covered in the next section. Personnel must be certain of the intent of the specifications.

B. Coating Coverage

Obtaining proper protective coating thickness and coverage is highly dependent upon the surface texture and/or profile of spray applied urethane foam. Therefore, it is important for responsible personnel to recognize that the actual surface area being coated, within given dimensions, varies with respect to the surface profile of the foam. Often the contractor may meet the rate of coating application required by the specifications, especially where a certain number of gallons per square is required, but may not have applied an adequate amount of coating to provide sufficient coating dry film thickness as outlined in Section IV.A. If the foam surface texture is "coarse orange peel" or worse, the coating applied will tend to be too thin on the high points and may actually "puddle" in the low areas. Obviously, the end result is a coating that is not of uniform thickness, which will usually lead to premature failure in service.

In addition to the uneven thickness of coating, noted above, application of coating over rough foam surfaces often creates other problems such as pinholes, voids (or "holidays"), and cracking. Occasionally, small areas of marginal coating coverage may be found on an otherwise acceptable application. In such instances the problem can usually be corrected by brush or roller application of additional coating, which can be worked down into small voids, crevices, and pinholes. Such corrective procedures should be limited to relatively small areas and not be permitted as major corrective action. The best assurance of uniform coating application, assuming proper spray techniques are employed, is to control the original foam application to assure acceptable surface texture through good inspection.

In terms of coating application technique, a good practice to follow in obtaining proper coating coverage is to apply alternate coats of material in a cross-hatch or so-called "north-south," "east-west" fashion. The latter procedure is frequently written into specifications. Figures 20 through 25 show appearance of coating sprayed over foam with various surface textures.

C. Coating Defects

In order to obtain the best possible protection of applied urethane foam in roofing systems by the coating material selected, assuming proper film thickness and coverage, it is important to avoid certain defects that can lead to premature failure of the protective coating. Defects that sometimes appear in the coating system are pinholing, blistering (lack of adhesion), and cracking.

1. Pinholing. Liquid coatings tend to flow into pinholes, blowholes, and crevices in the foam surface and later create pinholes in the coating, such as shown in Figure 26. Although it may appear that holes in the foam are covered initially as the coating is sprayed in place, air trapped in the holes by the wet coating often pressures through the coating as it begins to dry or cure. The surface tension and/or viscosity of the coating then prevents closure of the hole that is formed in the coating so that the defect remains. In some instances application of additional coating will close the pinhole; normally, however, continued application of coating will only magnify the pinhole condition.

The ability to cover pinholes will depend to some extent on the nature of the coating material itself. Factors such as viscosity, volume solids, solvent content, and thixotropy of various coatings account for the differences in ability to cover defects in the foam surface. The best solution to the above problem is to prevent the occurrence of surface defects in the applied foam through rigid inspection.

A frequent cause of pinholes in a coating stems from the coating itself. Although recent coating developments have eliminated most of the problem, it is important to understand that certain coatings are prone to pinhole development. Generally, coatings that are low in volume solids and high in solvent content, particularly organic solvents, are sensitive to pinhole formation. This type of coating must be applied in thinner coats to prevent pinhole formation, resulting in more coats to obtain desired film thickness.

Coatings with high solvent content and low volume solids applied in thick wet films tend to dry first at the surface, leaving wet coating below the surface. Depending upon air temperatures and/or solar conditions at the coating surface, solvent can be forced through the partially dried surface skin causing pinholes. Usually, the only solution for the problem described is for the contractor to adjust the technique of application. In certain instances it may be necessary to make application during periods of the day when surface drying can be minimized. Invariably the cause can be traced to excessive wet mil thickness.

Once pinholes are present in an applied coating system it is extremely difficult to correct the situation. Marginal problems can usually be corrected by screeding a compatible caulk sealant into pinholes or voids with a putty knife, permitting the sealant to set up and then applying additional coating over the repaired areas. It is not recommended that the latter procedure be permitted or used on a major scale. In any case, elimination of pinholes is important to prevent water entry into the foam. Also, since pinholes do not contain coating, the foam becomes subject to deterioration by sunlight as described in Section III.D. Eventually, this condition can undermine the coating system and lead to complete failure.

2. Blistering (Loss of Adhesion). Blisters can be caused by factors which do not relate directly to coating application. These factors concern such things as vapor transmission and choice of breathing or non-breathing coatings. In this section, it will be assumed that correct technical design decisions have been made and attention is directed to problems that must be considered at the time of coating application. As with good foam application, a properly cleaned, dry, sound surface is required to obtain good coating application. Anything that interferes with these elements can serve to create poor adhesion of the coating which will lead to formation of blisters or to conditions that might permit the coating to be stripped off the foam surface at a later time, leaving the foam unprotected.

Aside from obvious contamination such as dirt, grease, oil, and solvent spills, one of the most frequent causes of poor coating adhesion is deterioration of the applied foam surface due to sunlight. As described in Section III.D, excessive exposure of the foam surface to sunlight causes a breakdown of the surface, creating dusting and/or friability. Coating over such a foam surface can result in little or no bond of the coating to the foam. It was mentioned above that a dry foam surface is required, which is generally true and most desirable. However, it is important to point out that some of the newer aqueous or water-based coating systems can tolerate a small amount of dampness on the surface of coating application. The best procedure to follow is to check the manufacturer's recommendations with respect to the given coating system being applied. However, no application of any coating system should be permitted over obviously wet surfaces.

One additional condition that can cause adhesion problems with the coating is excessive foam overspray on the foam surface, as mentioned in Section III(2) of the guide. Excessive overspray creates an irregular surface that prevents uniform contact of the coating on the surface and can serve to cause "bridging" of the coating between small nodules of foam overspray.

3. Cracking. Coating cracks, crazing, "crow's feet," and "mud checking" at the time of coating application are predominantly due to poor foam texture conditions, excess wet film thickness or "puddling," improper temperatures, and exposure of the applied coating to excessive moisture before the coating is properly dried or cured.

Coating applied over coarse foam surfaces is usually non-uniform in thickness, which creates uneven stresses in the coating as it dries or cures. This factor in combination with temperatures that may be too hot or cold can serve to cause cracking of the applied coating. In some instances where foam texture is very bad, puddling of the coating will also take place so that as the coating dries or cures, shrinkage cracks, crazing, or "crow's feet" tend to develop. The latter effect will usually be observed to some degree where coating puddles form due to excessive application rates. Normally, puddling is most frequent adjacent to vertical surfaces such as parapet walls, cants, vent pipes, and equipment flashings. Short of puddling, the coating may tend to slump or run on vertical surfaces which creates nonuniform coating thickness, leading to the problems previously described.

It is difficult to be specific about the effects of temperature on an applied coating as it dries or cures, in view of many coating variables. Generally, aqueous or water base systems are more sensitive to cold temperatures, whereas organic solvent systems are more troublesome under hot conditions. In extreme conditions of cold temperatures, an aqueous coating may freeze before it is properly dried. A freezing or near freezing condition is normally accompanied by cracking and crazing. Also, the quality of the coating will be severely affected if freezing occurs before drying is complete, because the coating will not coalesce properly.

Hot temperatures with organic solvent coating systems tend to develop pinholes rather than cracking or crazing for the reasons explained in Paragraph 1 of this section. However, hot temperatures with aqueous coating systems can lead to any of the cracking effects mentioned above due to shrinkage caused by rapid drying at the coating surface. Deposit of moisture on an applied coating that is not thoroughly dry or cured is usually detrimental to any coating and will in many instances cause cracking. Aqueous based coatings are more susceptible to moisture and in some cases will be diluted and in extreme situations can be washed off the coated surface.

Aside from the obvious problems caused by poor foam texture or coating application techniques, the coating manufacturer's recommendations should be consulted to determine proper limits on drying or cure time, temperature, and moisture.

V. GRANULE APPLICATION

In recent years mineral granules spread into the final wet application of coating have been used to (1) reduce damage from foot traffic and other mechanical exposures; (2) increase hail resistance; (3) provide walkway surfaces around equipment; (4) improve overall appearance; (5) provide a broad range of colors; (6) serve as a base for color coat applications between materials otherwise incompatible; and (7) reduce bird pecking.

Certain coatings are more prone to foot traffic and other mechanical damage, and it was found that granules imbedded into the final wet coat served to harden the surface. An additional benefit has been increased resistance to hail damage in some situations. An extension of the concept has been to use granule applications in limited areas for walkways and around equipment installations, where frequent servicing is required. The use of granules in the latter instance has been found to diminish damage to urethane roofs in such service related areas. Another valuable aspect of granule applications has to do with the aesthetics or finished appearance of roof systems that are visible on various building designs. Granules, in this instance, eliminate flash marks due to spraying of both foam and coatings, thereby providing a smoother, more uniform appearance to the finished roof surface.

Granules also provide a means for obtaining a broad range of colors either through the use of colored granules or, where there is limited color availability in a selected coating, imbedded granules can serve as a base for application of a color coat material. Granules can also serve as a base or buffer for color coat applications between coating

materials that would otherwise be incompatible. An example of such an application is the use of silicone rubber coatings in which color is usually limited to white or gray and other coatings will not adhere to the silicones. In this case imbedded granules provide a base for applying a color coat material such as an acrylic.

A. Overall Roof Application

When granules are applied over the entire roof system, they are usually applied to the final wet coating. The method used is to alternately apply coating and granules as the work proceeds across the roof. After an area is coated, the granules are spread in such a way as to leave a clean wet lead edge of coating so that the next area of coating application can be tied in without spraying coating onto the granules in place.

B. Limited Service Areas

Granules used in creating walkways and service areas around equipment are normally placed into an additional coat of material applied over and above the specified coating system. Service areas are usually marked with chalk lines to identify limits of additional wet coating application, which can be accomplished by brush, roller, or spraying using a "picture framing" technique. Granules are then spread into the wet coating and left until the coating has thoroughly dried or cured. Subsequently, loose non-imbedded granules are swept up and discarded.

It is important to note that loose granules in limited service area applications should not be left to spread out over an otherwise non-granulated coated roof system. Loose granules can constitute an abrasive to the rest of the roof due to foot traffic which can cause penetration and wear of the coating system. This can be particularly severe when walkways and/or service areas are violated, which is often the case.

In some limited cases, granules can be hand applied, but most contractors use special spray equipment designed for the purpose. In most instances contractors use some type of modified sand blasting equipment. Equipment used to spray granules must typically be operated at relatively low air pressures to give the operator good control over the spread of granules. Excessively high pressure of the sprayed granule stream should be avoided to prevent penetration of existing dried or cured coating and/or to prevent the granules from bouncing back from the surface and falling back to the roof surface with no control. Another effect of high pressure in the granule spray stream is that the granules may tend to "tumble" in wet coating which leads to poor appearance and a generally poor application. The desired effect when spraying granules is for the granules to lose practically all their velocity out of the spray nozzle and "free fall" into the wet coating.

A good granule application is one where the granules are spread evenly and provide close to 100% saturation of the coated surface. Care should be taken to prevent voids or "shiners," as they are called in the trade. Obviously, it is important that granule application be made into the wet coating material to obtain proper bonding.

Normal applications of granules are in the magnitude of 40 to 50 lb/100 sq ft of surface. Figure 27 shows a properly granulated surface.

VI. APPLICATION IN SEVERE ENVIRONMENTS

As with many construction related activities, severe weather can cause serious problems during construction of urethane foam roof systems. The intent of this section is to suggest special precautions that may be necessary to cope with various environmental problems. It should be noted that, in general, accommodations which can be made to permit satisfactory application of foam will also provide for successful coating application. Therefore, the majority of comments in this section are directed to foam application problems.

Four basic factors that may be present in the environment that can affect application singly or in combination are: (1) moisture and/or humidity; (2) heat; (3) cold; and (4) wind.

A. Moisture and/or Humidity

In geographical areas where rainfall or snow is more or less constant at certain times of the year, the best results will be obtained by scheduling roofing work in the drier season. When this is impractical or impossible, methods are available to reduce the weather effects during roof construction. Temporary protection in the form of a "tent" or similar structure can be prepared and moved from point to point as the roofing progresses. The tenting material can be canvas or plastic film. Some "air structures" have been used in very severe situations, such as in construction of the foam roof over the Superdome. Air structures have been made commercially, but some contractors have built a structure by heat-sealing plastic film together into an inflatable cover. Some form of simple anchoring device such as a sand-filled fire hose has been used to create a continuous bottom edge seal. Relatively little air pressure is required for inflation and it can normally be provided with a simple squirrel cage blower. An air structure of the type described is simple to move and can be made into various shapes, depending upon the pattern selected. Air structures have two major disadvantages: (1) they are subject to wind limits based on design and inflation pressure and (2) contractor personnel spraying foam or coating within such a structure usually require supportive fresh air masks.

The factor of high humidity in itself is not usually a problem if the roof deck surface temperature is at least 5°F above the dew point as mentioned in Section III.C. When cold temperatures and high humidity are present together, either a structure must be used, or some means must be used to raise the temperature of the roof deck, if possible. As previously emphasized, the roof deck must be dry if a good sprayed foam roof system is to be constructed.

B. Heat

Application problems with respect to high heat conditions have been discussed for both foam and coating materials in Section III.C.3 and Section IV.C, respectively.

C. Cold

Unfortunately cold conditions for application of foam and coatings are often accompanied by moisture problems, as previously discussed. However, there are some situations where cold conditions prevail alone at temperatures of approximately 35°F or higher. Materials, equipment, and procedures are available to enable foam application at temperatures above 35°F. but the only practical way to apply foam below 35°F is to use heated space enclosures.

In discussion of foam application on cold surfaces in Section III.C.2, the problem of slow reacting foam was explained, and mention was made of a nominal lower surface temperature limit of 60°F for application of conventional foam systems. Some foam systems manufacturers provide specially catalyzed systems with a short cream time that produce enough chemical heat or exotherm to permit application of foam down to about 50°F surface temperatures. However, at surface temperatures between 35°F and 50°F a different technique must be employed to avoid the problem.

The usual approach is to employ what is called a "froth" spray foam. This technique requires a special adaptation of the spray foam equipment which permits controlled injection of small amounts of fluorocarbon blowing agent R-12, which has a boiling point of about -20°F, and a special foam system that will react properly in conjunction with with the R-12 material. The mixed foam composition pre-expands or froths as it leaves the spray gun and is applied to the cold surface. The froth composition serves to block or insulate the cold surface (heat sink) long enough to permit the chemical heat or exotherm generated to vaporize the R-11 blowing agent contained in the system, thereby providing a proper foam rise.

One additional technique that is used successfully in moderately cold conditions with availability of sunshine is to apply a black or dark colored primer on the roof deck. The application of such a primer can increase the roof deck temperature by as much as 20°F above the temperature that would exist otherwise, due to surrounding environmental conditions. The higher deck temperature also aids in obtaining a dry surface.

Other methods of raising roof deck temperatures are used occasionally, such as under deck heating with space heaters and top heating with electric insulating blankets. However, these methods are of limited and questionable practical value.

D. Wind

Wind tends to be the most variable factor at all times. It has been pointed out in Section III.2 that the practical limit of wind speed without special precautions is about 12 miles per hour, to avoid adverse effects on applied product quality and/or overspray. Due to variability of winds it is only under very special conditions that the use of structures of the type discussed in Paragraph A are employed or justified. It is obvious that if some type structure is erected for other environmental reasons, relief from wind is obtained. The primary approach to wind control that has been employed successfully is the use of portable windscreens. Such windscreens are usually in the form of a "picture

frame" or partition type construction, built from common lumber and then covered with fine mesh window screen, burlap, or netting. The purpose of these windscreens is to break the wind and still permit enough air passage to prevent a solid barrier to the wind, which would create a need for heavy construction and anchoring.

It is often convenient for purposes of stability and two direction wind protection to erect the windscreen in an el type configuration. Accordingly, the latter type construction can be hinged at the corner for ease of handling and movement. It is also possible, of course, to extend the above approach to a three or four sided construction if necessary. Usually anchoring of windscreens can be accomplished with sandbags, full 5 gallon material containers, or other readily available small heavy objects. The degree to which higher wind velocities can be tolerated will, of course, depend upon the sturdiness of the windscreen erected. Wind velocities beyond 25 miles per hour cannot be tolerated, in any case.

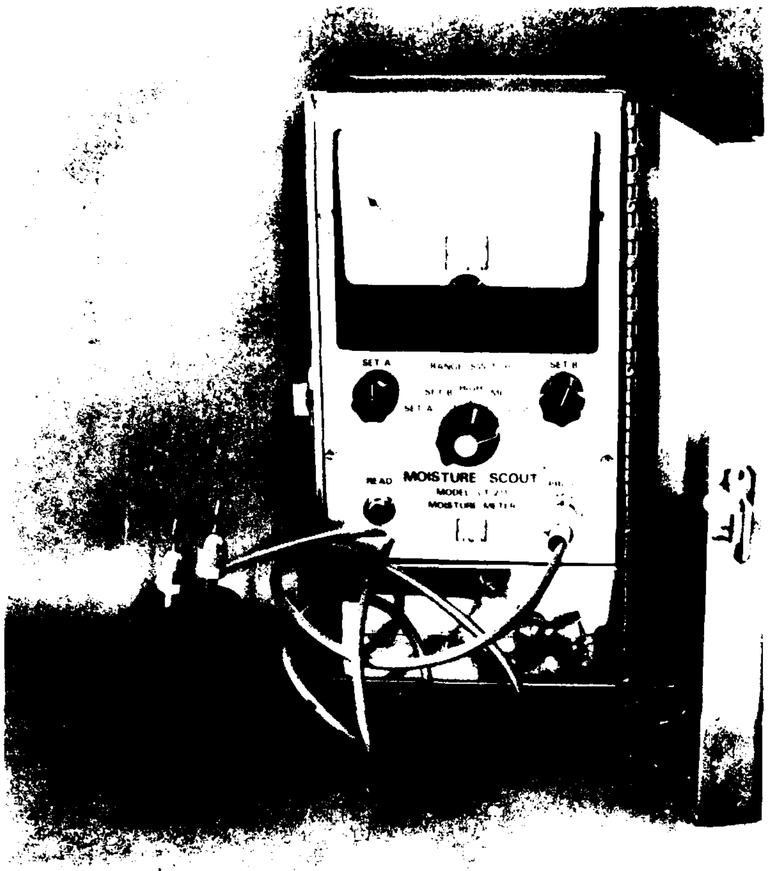

Figure 1. Moisture meter.

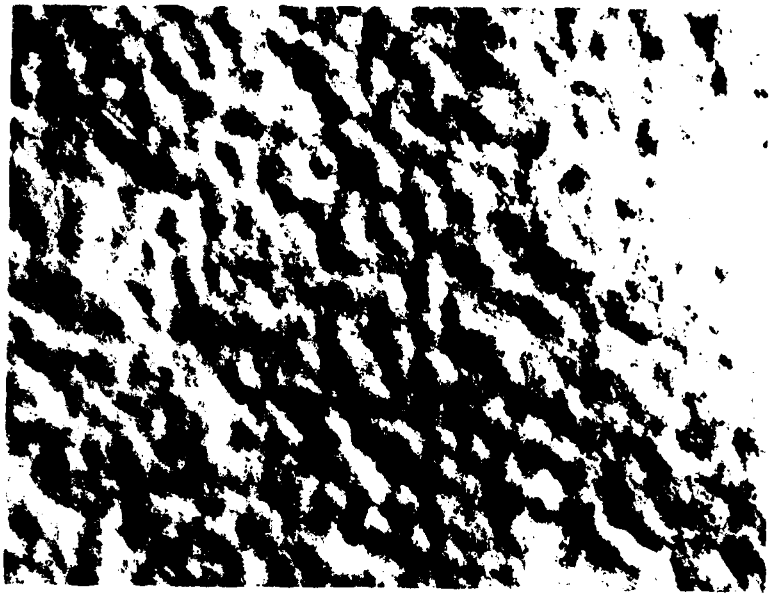

Figure 2. Smooth foam surface.

Figure 3. Orange peel foam surface.

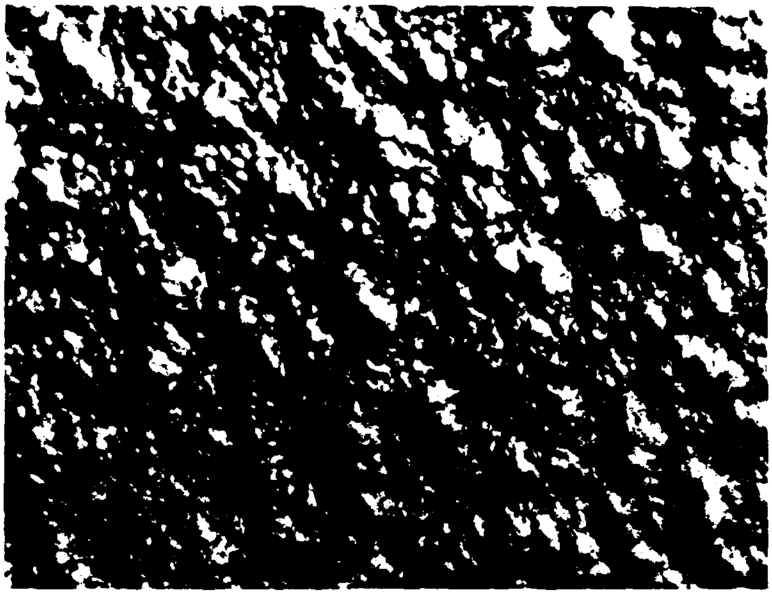

Figure 4. Coarse orange peel foam surface.

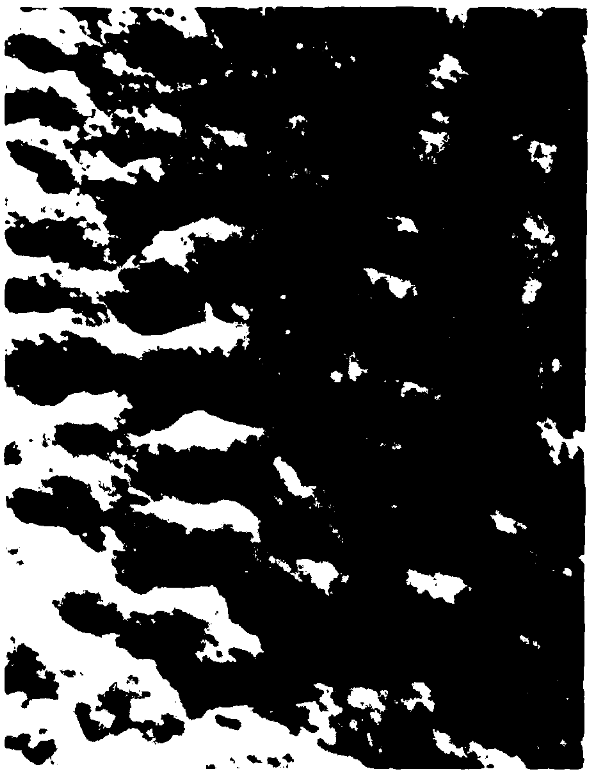

Figure 5. Verge of popcorn foam surface.

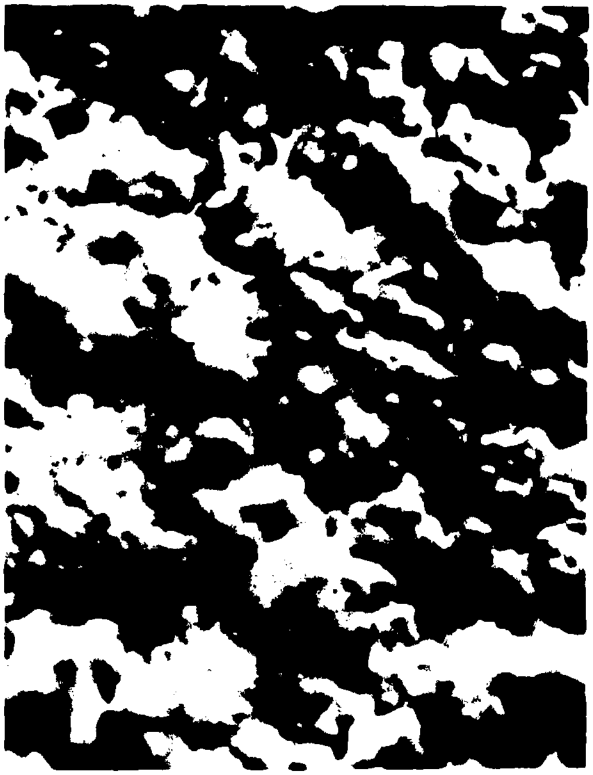

Figure 6. Popcorn foam surface.

Figure 7. Treebark foam surface.

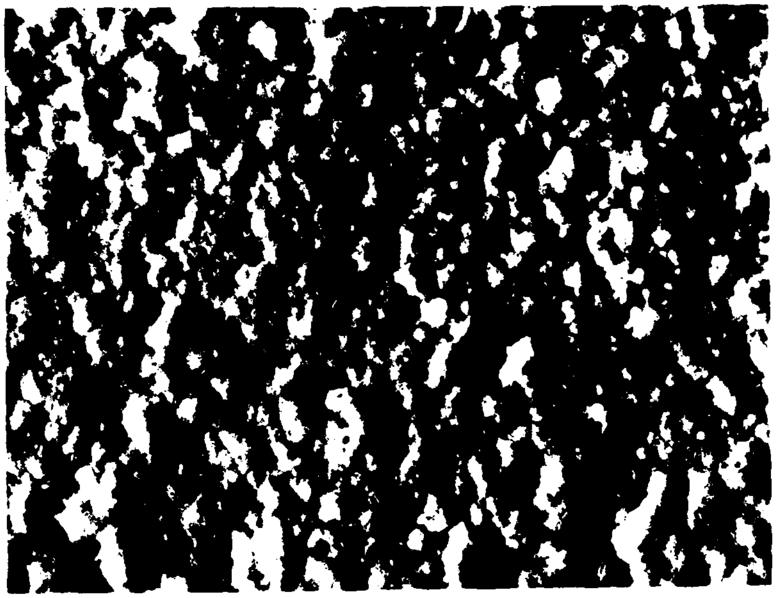

Figure 8. Pinholes or blowholes in foam surface.

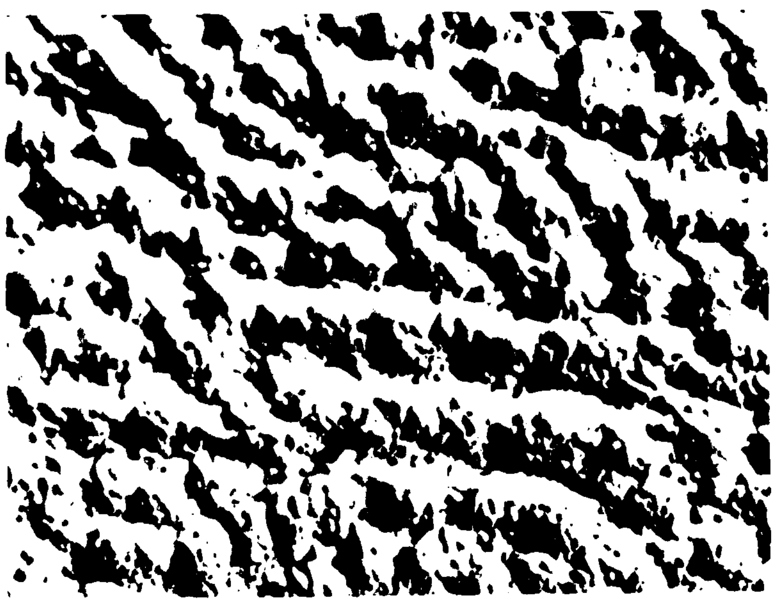

Figure 9. Rippling in foam surface.

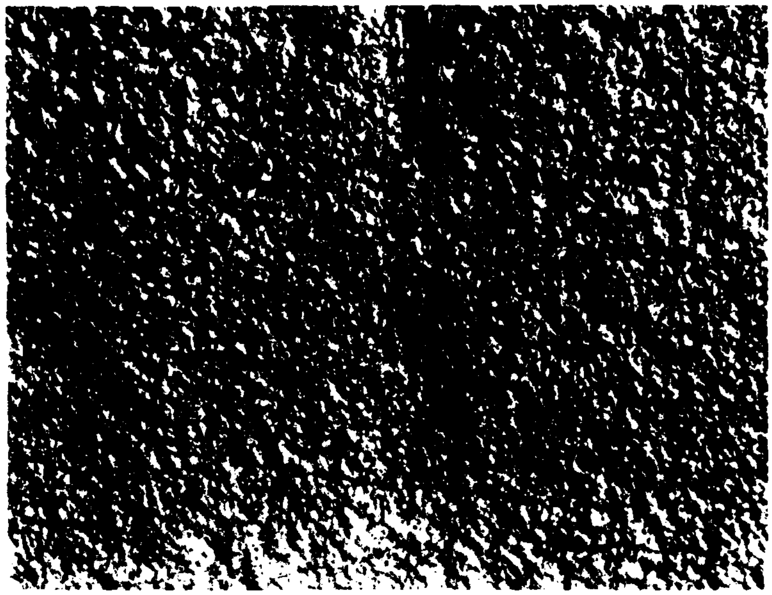

Figure 10. Isocyanate rich surface.

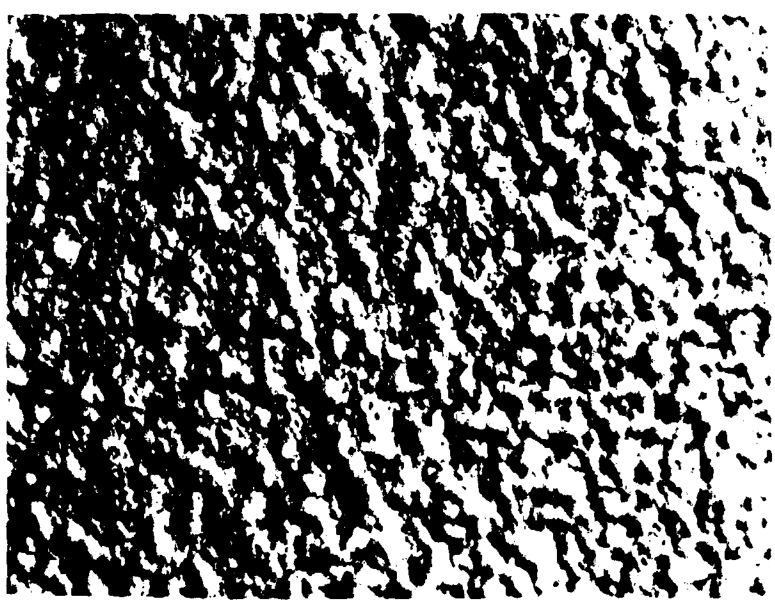

Figure 11. Resin rich surface.

Figure 12. Foam application over wet surface.

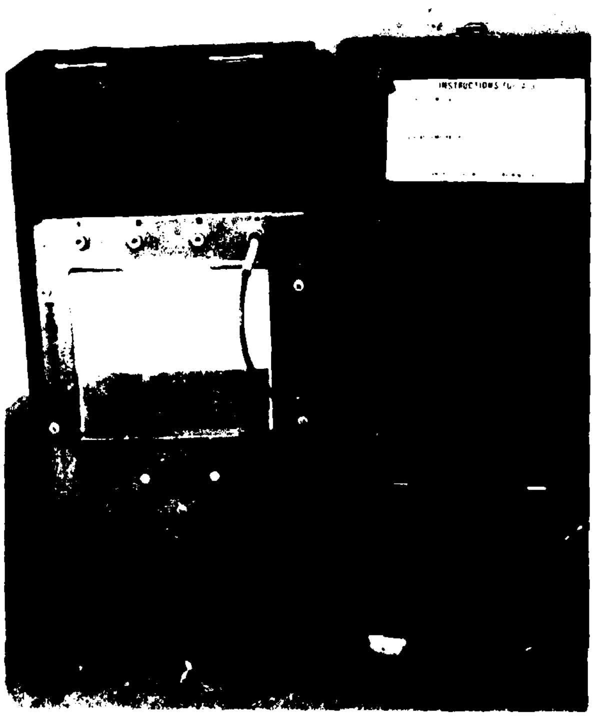

Figure 13. Pyrometer.

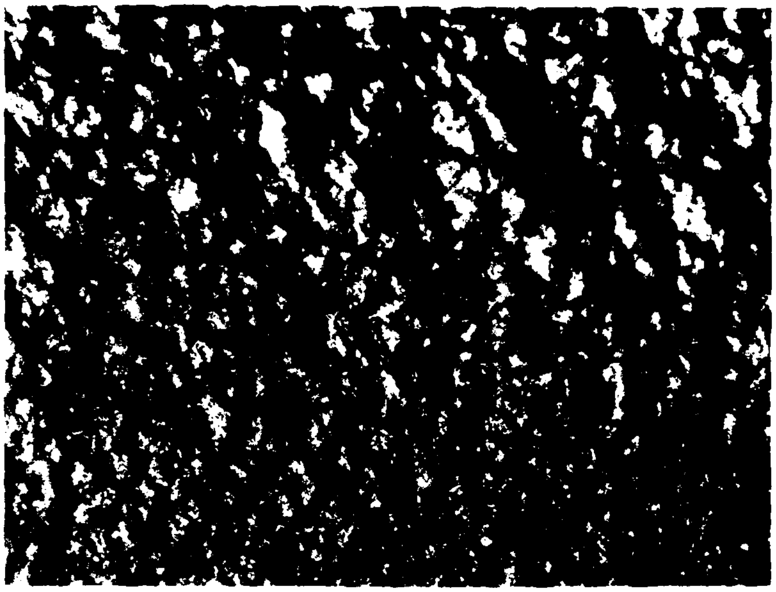

Figure 14. Foam application over cold surface.

Figure 15. Foam application over hot surface.

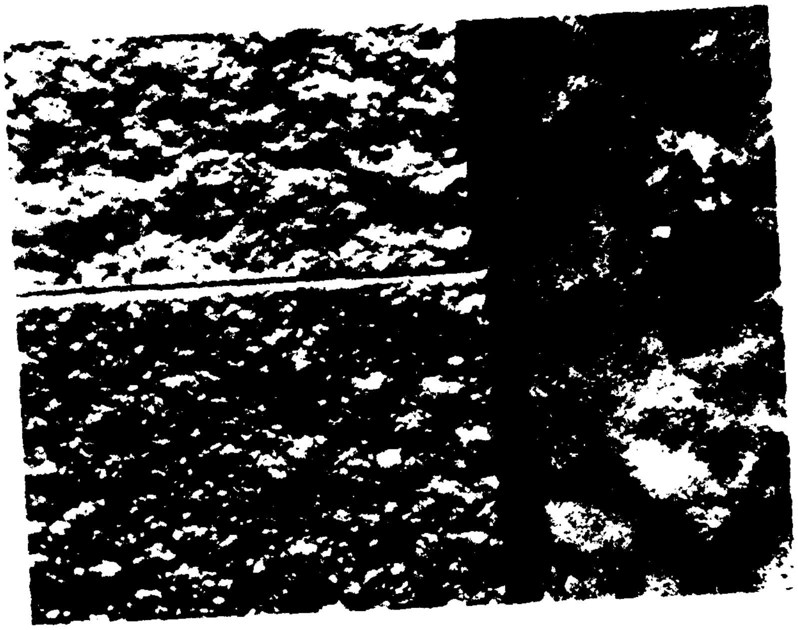

Figure 16. UV degradation of foam.

Figure 17. Wet film gauge.

Figure 18. Peak dry film thickness gauge.

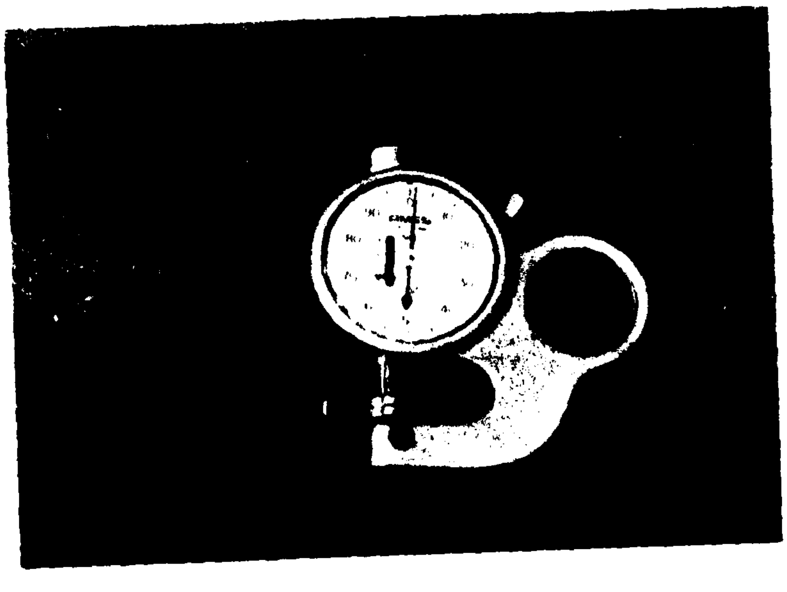

Figure 19. Ames dry film thickness gauge.

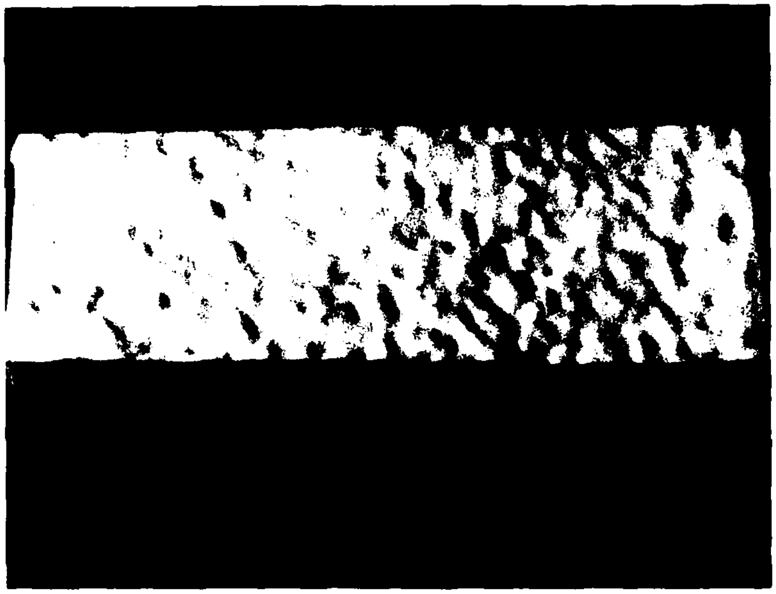

Figure 20. Coating over smooth/orange peel.

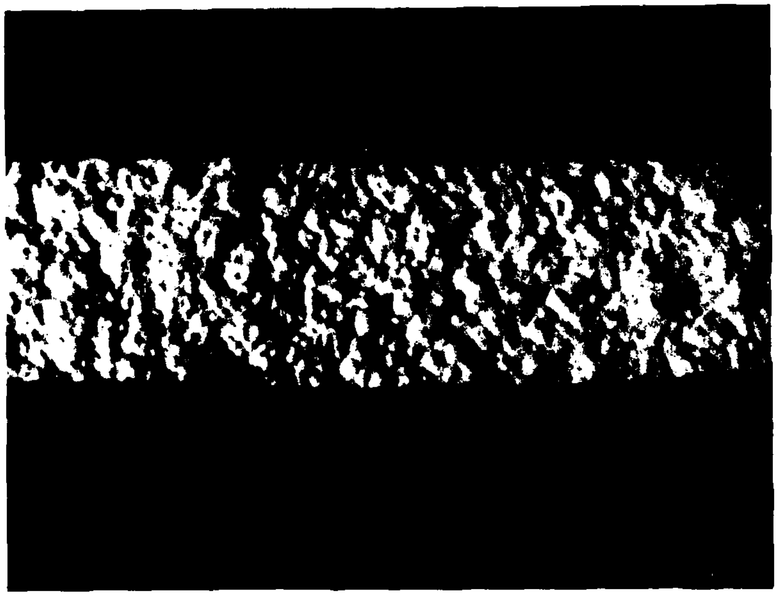

Figure 21. Coating over orange peel.

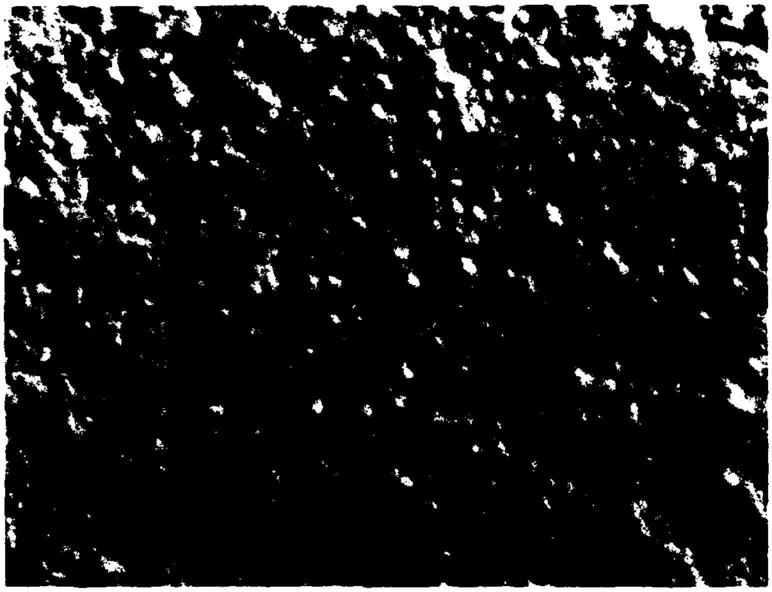

Figure 22. Coating over coarse orange peel.

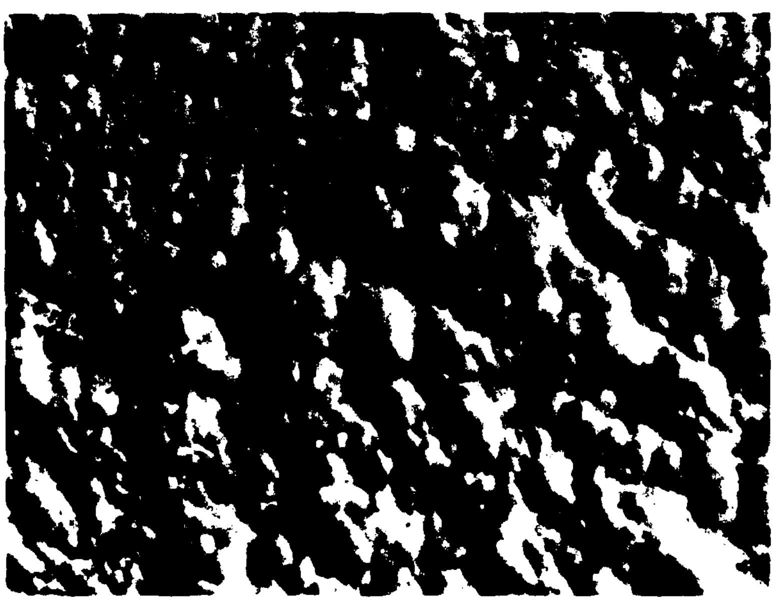

Figure 23. Coating over verge of popcorn.

Figure 24. Coating over popcorn.

Figure 25. Coating over treebark.

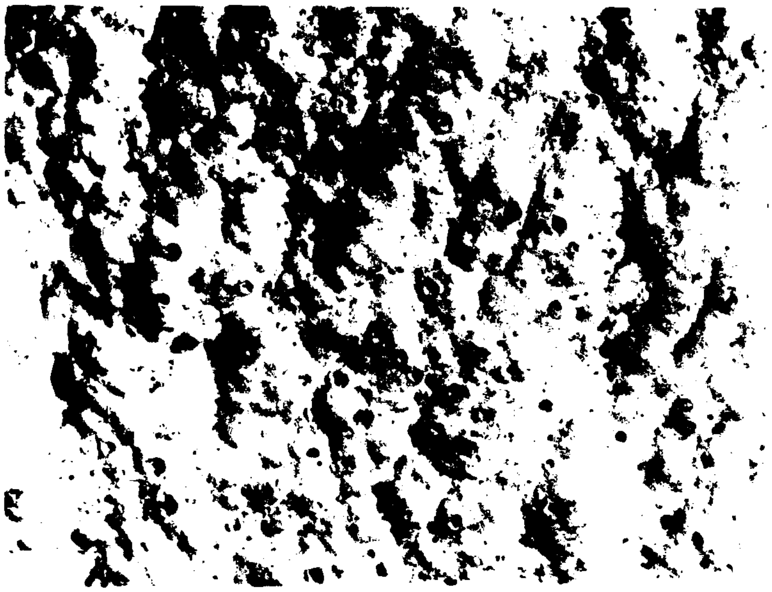

Figure 26. Pinholes in coating.

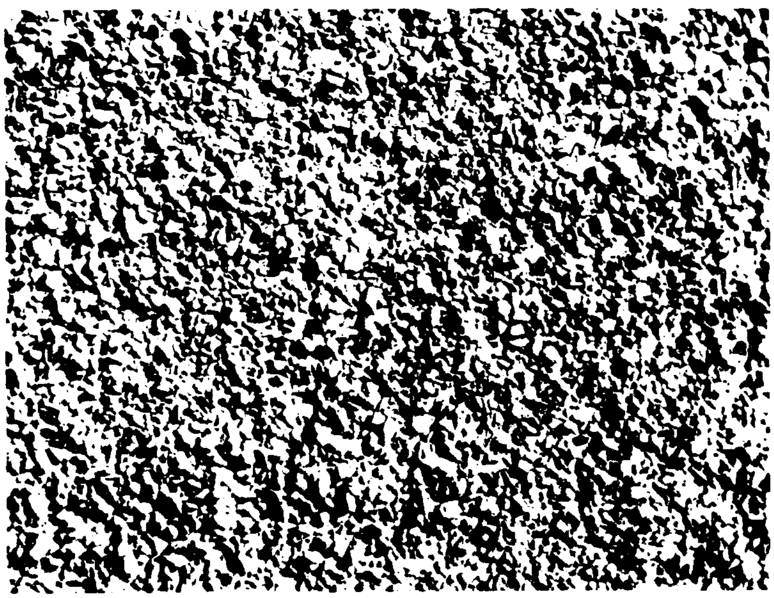

Figure 27. Granules over coating.